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BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

FIRES IN LAKE SUPERIOR IRON MINES

BY

EDWIN HIGGINS

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CONTENTS.

	Page.
Preface	5
Introduction	7
Mining methods on the Lake Superior iron ranges	7
Serious mine fires on the iron ranges	8
Notes on fires during 23 years	8
Causes of metal-mine fires	12
Causes of mine fires on the Lake Superior iron ranges	12
Principal causes of metal-mine fires	12
Fire prevention	12
Fire prevention at pump and shaft stations	12
Fire prevention in shafts	13
Fire prevention at shaft collars and headframes	13
Proper use of miners' lights	14
Fire patrol	15
Covering of steam pipes	15
Avoidance of accumulations of combustible material	15
Storage of lighting and lubricating oils	15
Posted rules and regulations	15
Summary of preventive measures	16
Fire-fighting appliances	16
Fire signals and fire drills	17
Oxygen-breathing apparatus	18
Gases encountered in mine fires	18
The use of animals in mine fires	20
Ventilation as affecting mine fires	21
Reversal of current	21
Sealing mine fires	22
Fires in the combustible black slates of the Menominee Range	22
Some recent fires	23
Fire at the Baltic mine	23
Fire at the Dober mine	23
Fire at the Florence mine	23
Fire at the Youngs mine	23
Fire in Bristol open pit	24
Descriptions and analyses of black-slate samples	24
Sample from the Dober mine	25
Sample from the Baltic mine	25
Sample from the Youngs mine	26
Second sample from the Youngs mine	27
Sample from the Bristol mine	28
Second sample from the Bristol mine	28
Third sample from the Bristol mine	28
Fourth sample from the Bristol mine	29
Fifth sample from the Bristol mine	29
Chief items of analyses	30
Causes of spontaneous ignition	30
Methods of preventing and fighting spontaneous fires	31
Acknowledgments	32
Publications on mine accidents and methods of mining	32

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ILLUSTRATIONS.

Page.

PLATE I. *A*, Collar of circular concrete shaft and part of steel headframe at mine near Vulcan, Mich.; *B*, Door of powder magazine of mine on Gogebic Range, fire extinguishers at hand ---------- 14

II. *A*, Fire in pyritiferous black slate in surface cave in mine near Crystal Falls, Mich.; *B*, Fighting fire in surface cave in mine near Crystal Falls, Mich ---------- 24

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PREFACE.

Few mines are free from all danger of fire. The danger to life and property may be reduced, but rarely eliminated, by fireproof construction in and about the shaft, as timber and other combustible material are requisite for the development of nearly all mines. In fact, in deep mines, such as some in the Lake Superior region, where the roof pressure is very great, it is not always possible to use rigid fireproof construction because of the gradual but irresistible movement of the rocks. Wherever fireproof construction is not possible in and about shafts, underground landings, and stables, other precautions, such as a good water-supply system consisting of pipe lines and hydrants, abundant hose, automatic sprinklers, and the organization of fire-fighting crews, are essential. Also treatment of the timber by zinc silicate or common salt solutions not only preserves the timber but makes it much less inflammable.

Careful watch should be kept of such sources of ignition as the careless use of candles or other open lights or of material that might lead to spontaneous fires, such as oily waste or manure. Also to be avoided are careless electric installations or short circuits due to the crushing of timbers.

A small quantity of combustible material, if ignited, may cause most serious consequences. A few years ago in a certain western mine, in the development of which all reasonable precautions had been observed, a small pile of loose timbers, inadvertently left at the bottom of a winze, was in some unknown way set on fire. It burned itself out in half a day without damage to the mine, yet many of the miners were killed by the gases produced.

With such an example it is felt that hardly any mine is invulnerable to fire. The Bureau of Mines has therefore given much attention to the investigation of mine fires, and contemplates the issuance of a series of publications on this subject. A preliminary technical paper[a] and a miners' circular[b] covering the general features of mine

[a] Rice, G. S., Mine fires, a preliminary study: Technical Paper 24, Bureau of Mines, 1912, 51 pp., 1 fig.

[b] Paul, J. W., Mine fires and how to fight them: Miners' Circular 10, Bureau of Mines, 1912, 14 pp.

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fires have already been issued, but they are to be supplemented by publications dealing with the specific mine-fire problems in various mining districts. The following paper by Mr. Higgins is the first of that series. The list of fires in the Lake Superior iron ranges since 1890, many of which have occurred in well-equipped mines, certainly indicates the necessity for great care to prevent recurrences.

One of the most interesting features of Mr. Higgins's investigations concerns the fires in the carbonaceous and pyritic wall-rock slates of the Menominee range. These are sometimes so combustible that spontaneous fires may result when broken masses are exposed to the weather, as in the surface caves. When the caves are connected with the underground workings, as they are in many mines, it is obvious that such fires are a serious menace to the mine, because of the possibility either of the fire extending into the mine, or of the fumes being drawn into it by the ventilation. When this latter condition is liable to occur, it may be necessary to install pressure fans to force the fumes back while the fire is being fought in the cave. Where the caving system is used, the problem is liable to become more and more serious as the caves become deeper.

GEORGE S. RICE.

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FIRES IN LAKE SUPERIOR IRON MINES.

By Edwin Higgins.

INTRODUCTION.

Many mine fires have occurred on the Lake Superior iron ranges during the past 25 years. Some of them have resulted in serious loss of life and property. Certain operators, especially those who have experienced losses, realize the danger of underground fires and have adopted preventive and protective measures. There are others, however, who have not given the matter much thought, or who do not appreciate the necessity of special precautions for protecting their mines against fire. This feeling of safety is caused by the fact that many of the mines have had no fires during periods of 20 to 30 years.

The purpose of this paper is to awaken the operator to the ever-present danger of fire underground. Most of the suggestions regarding prevention and protection are old and well known, and although some of them are at present in use, there are still a great number of mines provided with little or no protection.

Except in the discussion of fires in the combustible black slates of the Menominee range, this paper will deal only with fires originating at or near the collar of the shaft, in the shaft, or underground. All statements refer to conditions as found on the Lake Superior iron ranges, although they may be applicable to other metal-mining districts.

MINING METHODS ON THE LAKE SUPERIOR IRON RANGES.

For the benefit of those not familiar with the mining methods of the Lake Superior iron ranges it is deemed well to outline in a few words the systems in use. The commercial ore varies from 10 to 400 feet or more in width, the ore bodies varying from the flat deposits of the Mesabi range through all gradations of dip up to the steeply inclined and vertical veins of the other ranges. With regard to hardness of ore and walls almost every conceivable condition is to be found; hence great variation in mining methods is necessary.

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For the purpose of this paper it seems necessary only to divide the mining methods into those in which little or no timber is required and those in which much timber is used. In the hard-ore mines, where conditions permit, the ore body is mined by some form of underhand, breast, or back stoping, the stopes being left open, little or no timber being used, or filled with waste rock. With such stopes there is practically no danger of fire in the mine workings.

If the ore or the walls of the ore body, or both, are of such character that the ground will not stand without timber, some form of top slicing or sublevel slicing and caving is usually adopted. These methods, with their many variations, necessitate the use of a vast amount of timber, practically all of which remains in the mine.[a] As mining progresses the timber crushes and forms a mat that serves as a barrier between the mine workings and the waste rock settling from above. The mat, which includes some waste rock, constantly increases in thickness as mining goes downward, so that in the course of time it may become several hundred feet thick.

Most shafts are lined entirely with timber. Some have steel sets with timber lagging and others are of steel and concrete construction throughout.

SERIOUS MINE FIRES ON THE IRON RANGES.

Owing to the lack of detailed records the following statistics of past mine fires on the iron ranges are not claimed to be complete. As in numerous cases no record whatever has been kept, probably only a small proportion of the fires that have occurred are mentioned herein. However, it is believed that most of the important fires are included.

Regarding the frequency of mine fires, it is noteworthy that on April 30, 1913, the Tilden fire started; that on May 3, 1913, the Malta fire occurred; and that a few days later a fire (quickly put out with a chemical extinguisher) was reported at the Newport mine. Although this record is exceptional for such a short space of time, it is mentioned for the purpose of emphasizing the need of fire protection.

NOTES ON FIRES DURING 23 YEARS.

Statistics of some of the mine fires that have occurred during the past 23 years are given below:

March, 1890. B shaft, West Vulcan, Mich. Fire started just above sixth level, 400 feet from surface, and burned all timber above this point, as well as headframe. Cause not known, but thought to have been from fire built by shaftmen for warming their hands. No lives lost.

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[a] See Vallat, B. W., The Newport iron mine: Trans. Am. Inst. Min. Eng., vol. 42, 1911, p. 676; also Williams, P. S., Underground methods of mining used on the Gogebic range: Proc. Lake Superior Min. Inst., vol. 15, 1910, p. 179.

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January 29, 1891. Chapin mine, Iron Mountain, Mich. Fire discovered in haulage house, sixth level, near C shaft. Water introduced into shaft served only to reverse air current. Shaft finally sealed. Cause unknown, but probably from small oil stove kept in haulage house for warming oil. Three lives lost.

January, 1897. Adams mine, Eveleth, Minn. Fire started in the pump house of No. 1 shaft, just below the station, at a depth of 115 feet. Supposedly of spontaneous origin. Fire fought with water from hose; burned out without destroying pump house. No fatalities.

1898. Pewabic mine, Iron Mountain, Mich. Fire discovered in a room on the fifth level, midway between two shafts. Could not be reached with water on account of gas. Shafts sealed. Cause not known, but though to have been from candle used to heat oil. No lives lost.

June, 1898. Adams mine, Eveleth, Minn. Fire started in pump house at 125-foot level, No. 2 shaft. It was caused by the overturning of a lantern containing kerosene. This fire was not fought. Several men were slightly burned when the skip dropped through the burning shaft. No fatalities.

July 28, 1900. C shaft, Vulcan, Mich. Gas from smoldering ashes dumped into open pit found its way to pump station through crosscut and affected pump men for three days. One death.

No date recorded. No. 3 shaft, East Vulcan mine, Vulcan, Mich. Fire started few feet below adit connecting with shaft 50 feet from surface. Headframe and 150 feet of shaft timber burned. Fire fought with water and finally extinguished by caving ground. Caused by lightning during heavy storm. No lives lost.

March, 1901. Curry shaft, Vulcan, Mich. Fire started in pump station on bottom level, 700 feet from surface. Shaft immediately sealed and water introduced. Mine reopened in 10 days. Cause unknown. No lives lost.

June, 1901. Chapin mine, Iron Mountain, Mich. In B Ludington shaft the explosion of an unknown quantity of powder caused the deaths of eight men, either from suffocation or carbon monoxide poisoning. Cause unknown, possibly from a fire.

October, 1901. Elba mine, Gilbert, Minn. Fire discovered in steam-heated powder thawer on main tramming level, 200 feet from surface. In some way the wood was ignited while pipemen were making repairs. The fire burned 48 hours, consumed about 50 feet of drift timber, and caused the loss of one life.

January, 1902. No. 6 shaft, Adams mine, Eveleth, Minn. A candle left on a shaft timber started a fire about 125 feet from surface. Fire was extinguished by throwing snow on it. The shaft was downcast and snow had collected on the timbers. There were no fatalities.

May 8, 1902. No. 2 shaft, Vulcan, Mich Fire started 75 or 100 feet from surface. Fought with water, but burned about five days, destroying 300 feet of shaft timber down to water. Thought to have been caused by sparks from locomotive on surface. No lives lost.

No date recorded. No. 6 shaft, Adams mine, Eveleth, Minn. Fire discovered in station on second level, 145 feet from surface. Probably caused by lighted candle left on timber near a small hoist. The shaft was sealed, a steam pipe, with an elbow, was lowered to a point opposite the fire, and steam blown in for 15 hours. Shaft was then reopened and fire extinguished with water from hose. No fatalities.

February, 1904. No. 3 shaft, Spruce mine, Eveleth, Minn. Fire started 185 feet from surface, by a candle left in a small shanty built on the plat to keep water off of pumpmen working 90 feet below. Fire quickly spread to the shaft

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timbers, and was fought 7 hours with two streams of water, after which all but two of 14 men, who were confined below the fire, were rescued. These two men were overcome and drowned.

September 17, 1907. Malta mine, Gilbert, Minn. Fire originated in mule barn about 600 feet from the hoisting shaft, supposedly caused by a man falling asleep in the barn and leaving his candle near inflammable material. The fire burned 48 hours, consuming all the timber around the shaft and interrupting production at this point for 10 days. Three lives were lost.

December 28, 1907. Lincoln mine, Virginia, Minn. Fire started in a shanty near the timber shaft, on the fourth sublevel, probably from a candle left burning in the shanty. The fire, which was fought with streams of water from surface, burned 24 hours, consuming shaft timbers and shaft house. There were no fatalities.

March 15, 1908. Tilden mine, Bessemer, Mich. Fire started in a sublevel above the eleventh level, 1,000 feet east of No. 6 shaft and about 600 feet from surface. Shafts sealed. Cause unknown. Miners were using candles for lighting. One life lost.

August, 1908. Adams mine, Eveleth, Minn. A candle left near an ore chute started a fire in No. 6 shaft. It was extinguished after seven hours' fighting with water. There were no fatalities.

July 2, 1909. Newport mine, Ironwood, Mich. Fire discovered in station at sixteenth level, D shaft. Shafts sealed and reopened in 36 hours; fire was still smoldering. Finally put out with chemical extinguishers. Cause unknown. Miners were using candles. One life was lost.

September, 1909. Aragon mine, Norway, Mich. Fire discovered 15 feet east of No. 4 shaft, on the ninth level. Hose connected at station and fire extinguished after two hours' fighting. Cause unknown. Miners used torches. No lives lost.

December 7, 1909. East Norrie mine, Ironwood, Mich. Fire started in square-set timbers on sixteenth level, midway between C and D shafts. Burned two days. Extinguished by flooding level with water. Cause unknown. Miners were using candles. No lives lost.

1909. Ironton mine, Bessemer, Mich. Fire discovered in pump station on thirteenth level, 50 feet north of No. 4 shaft. Burned three hours. Extinguished with water. Cause not known, but thought to have been a candle that dropped from a timber and set fire to a tool box. No fatalities.

March 10, 1910. Newport mine, Ironwood, Mich. At 3 p. m. fire was started in an ore chute between the eighteenth and nineteenth levels, near K shaft, by a miner throwing a lighted paper down the chute to ascertain how much ore remained therein. Fire could have been extinguished by the trammer had he dumped a car or two of ore into the chute, but instead of doing this he went in search of the shift boss. The fire was finally extinguished at 4 a. m. the following day by the use of water, after several men had been overcome while fighting it. No lives lost.

March 25, 1910. Windsor mine, Hurley, Wis. Fire started in pump station on fourteenth level, burned the timber of two levels, and died out in about two days on account of wet timbers. Cause unknown. Pumpman and helper, the only men in mine when fire started, lost their lives.

March 5, 1911. Smith mine, Gwinn, Mich. Fire started in timber and lagging on first level, 100 feet from shaft and 400 feet from surface. Fire sealed off. Cause not known, but supposed to have been from torch that either caught fire or exploded, throwing kerosene over the timber. One of two men who went down to work on pumps lost his life.

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May, 1911. No. 2 shaft, Hartford mine, Negaunee, Mich. Fire started in shaft between second and third levels, about 625 feet from surface. Fire could not be reached from below. Water column was broken and water allowed to run into shaft. After about three minutes pumps stopped. Fire burned three days, being finally extinguished with water. Cause unknown, but thought to have been from defective wiring or from candle snuff thrown into pocket at station. Although there were two escape shafts, seven lives were lost in getting the men out of the mine.

August, 1911. Lincoln mine, Virginia, Minn. This fire, presumably caused by a candle left burning on a timber, started on the first level, near the powder house. All shafts were sealed for three days, then fire was extinguished with water from hose. One hundred feet of timbering was consumed. There were no fatalities.

October, 1911. Newport mine, Ironwood, Mich. Fire started in K shaft at eighth level. Cause unknown, but probably defective wiring. Fire first fought from below, with little success. Shaft finally sealed and water turned into air pipes. Fire burned to the fourteenth level of the shaft, destroying every station. No lives were lost.

October, 1912. No. 1 shaft, Caspian mine, Palatka, Mich. At about 6 p. m. fire was discovered in headframe. Shaft house destroyed, two skips dropped to bottom of shaft (about 300 feet), and crusher dropped near shaft collar. Fire caused by sparks from steam shovel working during high wind about 100 feet from shaft collar. No lives lost.

August 26, 1912. Bangor mine, Gilbert, Minn. Fire started in mule barn about 300 feet from hoisting shaft, supposedly by some one dropping a lighted candle. The fire was extinguished in 45 minutes. Two mules were smothered. No human lives lost.

April 30, 1913. Tilden mine, Bessemer, Mich. Lagging near collar of No. 9 shaft caught fire just after day shift went down. Flames quickly spread to wooden shaft house, boiler, and engine house, destroying them. Shaft burned or wrecked to bottom. Fire sealed off by caving of shaft, and bulkheads put in underground by men wearing oxygen-breathing apparatus. Fire probably caused by match or burning tobacco dropped on lagging. A high wind was blowing. No lives lost.

May 3, 1913. Malta mine, Gilbert, Minn. Fire started in pump station of 50-foot shaft. Shaft totally destroyed. Fire probably caused by candle left in pump station. No lives lost.

May, 1913. Newport mine, Ironwood, Mich. Fire discovered in timber of crosscut on seventeenth level, east of D shaft. Put out with chemical fire extinguisher before headway was gained. Probably caused by carbide lamp being hung on timber. No fatalities.

Of the 31 fires mentioned above, 14 were probably due directly or indirectly to the use of candles and 19 started in or within a few feet of the shaft. Twenty-two lives were lost. In considering the foregoing record, one should remember that it is far from complete. Eight lives were lost in the powder explosion at the Chapin mine, but that disaster can hardly be classed as a fire, although possibly the explosion was caused by fire. During the past three years there were nine fires, involving the direct loss of eight lives and of property to the value of many thousands of dollars. Much additional loss resulted from the suspension of mining operations.

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CAUSES OF METAL-MINE FIRES.

CAUSES OF MINE FIRES ON THE LAKE SUPERIOR IRON RANGES.

From a review of the foregoing statistics of mine fires, the following list of known and suspected causes may be prepared:

Dropping candle in or near combustible material.
Use of oil stoves for heating oil for torches.
Building fires underground.
Dropping lighted paper in raise.
Dropping candle in ore pocket.
Explosion or ignition of kerosene torch.
Defective wiring.
Overheating of bearings of machinery.
Smoking underground or near shaft collar.
Lightning.
Sparks from locomotive or steam shovel.

PRINCIPAL CAUSES OF METAL-MINE FIRES.

Condensing the above list somewhat, and adding to it other known causes, the following may be set forth as the principal causes of all metal-mine fires:

Careless use of lights underground or at shaft collar.
Defective electric wiring.
Spontaneous combustion from friction in shaft rollers or underground machinery.
Spontaneous ignition of combustible rock.
Dropping lighted paper in ore chute.
Building small fires underground for any purpose.
Dumping ashes in open pits connected with underground workings.
Careless use of matches.
Incendiarism.
Smoking in timbered places near shaft collar or underground.
Sparks from surface engines of any kind or from surface fires.

FIRE PREVENTION.

In adopting measures for the prevention of underground fires the aim should be to remove, as far as conditions will permit, the causes of fires and to provide means for quickly subduing an incipient blaze.

Statistics of metal-mine fires from all over the world show that the great majority of fires originate in the shaft or pump station, in the shaft proper, or at or near the shaft collar. Hence, it appears that fire prevention is of greatest importance in these places.

FIRE PREVENTION AT PUMP AND SHAFT STATIONS.

Pump and shaft stations cut out of the solid rock or constructed of steel and concrete present the minimum danger. Even in such stations it is well not to neglect the ordinary precautions for fire prevention.

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In stations supported by timber the following suggestions are offered: Do not allow combustible material of any kind to collect; do away with open lights as far as possible; use care in electric wiring; have separate receptacles for clean and oily waste; do not place machinery close to dry timber. In the case of the pump station, if conditions do not warrant steel and concrete construction, at least break the continuity of the timbering between the station and the shaft. If support is necessary, a few sets of steel will serve the purpose.

FIRE PREVENTION IN SHAFTS.

Obviously, the steel and concrete shaft (Pl. I, *A*) is safest. There are a few shafts of such construction either in use or in process of being sunk. If timber is used the dry shaft is, of course, in the greatest danger, although the wet shaft is not immune from fire. There are certain fire-resisting materials, such as zinc chloride, that may be employed, if desirable, to render shaft timbers less inflammable. Dry shafts should be sprinkled with water at sufficient intervals to keep the timber at least damp. The sprinkling may be accomplished by various means. If a separate water line from the surface is provided the pipe may be tapped every 100 feet and a valve and a 50-foot length of hose supplied. If sufficient water is encountered in driving the workings, the water column may be tapped as described above. Some types of special sprinkling devices are efficient. Any system that provides for wetting the shaft timbers acts as protection as well as prevention.

A certain mine on the Gogebic range has had in use for some time a device for spraying the shaft. The water column is tapped every 50 feet. Owing to the high water pressure, a special pressure-reducing valve is attached. Connected to this valve are four jets, pointing in different directions, so that all parts of the shaft may be reached by the water. The handle of each valve is securely attached to a ⅜-inch steel cable, and this in turn is connected with a lever at the shaft collar. The lever may be operated by one man and all of the valves opened simultaneously. The shaft has a dip of 75° and is about 1,100 feet deep.

Care should be used in all electric wiring; rollers, where used, should be kept well oiled; candle snuffs or any form of open light should not be left on or near the timbers; steam pipes should be covered or kept well away from timbers.

FIRE PREVENTION AT SHAFT COLLARS AND HEADFRAMES.

Any wooden structures at or near the shaft collar (especially shaft houses of wood) are dangerous. The safest construction is the all-steel headframe, with steel and concrete shaft collar to a depth

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of 25 feet or more. Headframes and shaft houses of wood are still in use at a great many mines, but in most of the new construction steel is used. In cases where conditions do not warrant tearing down the wooden structure the danger may be lessened by concreting the shaft for several sets below the collar and providing an iron door for covering the shaft in case of fire in the headframe.

PROPER USE OF MINERS' LIGHTS.

Carbide lamps, candles, and different types of wick-burning lamps are the types of lights used by the miners in Lake Superior iron mines. The carbide lamp is rapidly displacing the other types; on some of the ranges it is used almost exclusively. Directly or indirectly, candles have probably been the cause of a large proportion of mine fires. The candle burns with an upright flame, consumes more oxygen than does the carbide lamp, and is at least twice as costly per man per shift. Of the three classes of lights, candles are most likely to be left burning in the working place when the miners go off shift.

The greatest danger is from the candle snuff, which may be left or may drop on or near combustible material. A method of lighting sublevels still practiced in some mines is to place a candle between two nails driven into the timber. The danger here is from the candle leaning against the timber, or from the dropping of the snuff on or near combustible material. In nearly every mine where this practice is followed the timber is found to be charred. In several instances the snuff has been watched as it fell from between the nails; it usually remained lighted. Solid-bottom sconces are an improvement over the nail supports, but the writer believes that the best remedy is to do away entirely with candles as means of lighting in timbered mines.

Wick-burning lamps burn with a long, smoky flame and are liable to catch fire; however, they are usually taken from the mine at the end of a shift.

Carbide lamps give a stronger light and consume less oxygen than do either candles or wick-burning lamps. In regard to safety, efficiency, and cost the carbide lamp appears to be the most desirable type of light for the miner. Owing to the prejudice of some miners trouble is sometimes experienced in introducing carbide, but the prejudice may be overcome by a little diplomacy. Again, there may be some trouble at the start in getting the best results from the lamps, but experience has shown that these troubles are short lived and soon become almost negligible. Although carbide lamps are a great improvement over candles, there is still room for improvement in the method of lighting metal mines. A simple, inexpensive, and efficient lamp with an inclosed flame would approach nearer the ideal. It

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A. COLLAR OF CIRCULAR CONCRETE SHAFT AND PARTS OF STEEL HEADFRAME AT MINE NEAR VULCAN, MICH.

B. DOOR OF POWDER MAGAZINE OF MINE ON GOGEBIC RANGE, FIRE EXTINGUISHERS AT HAND.

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is possible that a portable electric light will produced that will fill this ideal. The electric lamp is now being extensively introduced in coal mines.

FIRE PATROL.

A fire patrol, covering all parts of the mine where timber is used, is recommended. Although a patrol is a wise precaution under almost any conditions, it is especially desirable in timbered mines that are dry. Provision for a fire patrol may be made without much additional cost by using for the work men whose other duties do not consume the entire day.

COVERING OF STEAM PIPES.

As a matter of economy, as well as fire prevention, steam pipes should be covered, especially where they must be laid close to timbering or lagging. The heat of uncovered steam pipes naturally tends to dry wood and render it liable to ignite when an open light is brought close to it.

AVOIDANCE OF ACCUMULATIONS OF COMBUSTIBLE MATERIAL.

Combustible material, such as dry wood, powder boxes, candle boxes, paper, hay, waste, or manure should not be allowed to collect in any part of the mine, especially at or near shaft and pump stations. A match or light of any kind dropped into a pile of such rubbish will start a fire readily.

STORAGE OF LIGHTING AND LUBRICATING OILS.

Large quanties of lighting or lubricating oils should not be stored underground. If it is necessary to store such material, provide a safe place removed from timbered places. In heating oils for use in wick-burning lamps do not perform the operation near combustible material. In oiling machinery care should be exercised not to spill the oil on near-by timber. Cars should be oiled at a place especially provided for that purpose—not anywhere a motor or train of cars may happen to lie.

POSTED RULES AND REGULATIONS.

A study of the causes of mine fires, together with a consideration of conditions existing at any one mine, will enable the official to prepare a suitable set of rules and regulations for the prevention of fire. Such rules should be worded simply and should be posted in conspicuous places. Above all things, they should be rigidly enforced.

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SUMMARY OF PREVENTIVE MEASURES.

Do not use candles for lighting underground.

As far as possible, do away with timber construction in head frame, shaft collar, shaft, shaft station, and pump house.

Keep shaft rollers and other machinery well oiled.

Break continuity of timbering from pump house to shaft.

Dry, timbered shafts should be kept moist.

Do not allow combustible rubbish to collect underground.

Beginning at the shaft collar, do not allow smoking in any timbered place.

Make rules and enforce them.

Use care in electric wiring and guard against short circuiting by frequent inspection.

Do not use kerosene in lanterns or torches—if it is necessary to have them, use a heavy oil.

Do not allow the building of fires underground for heating.

Cover steam pipes laid near timber.

Do not store lubricating or illuminating oils in great quantity underground, especially in timbered places.

FIRE-FIGHTING APPLIANCES.

Below are suggested protective measures applicable to practically all mines. Although they may not all be necessary for any one mine, the list is suggestive and from it an effective system of fire protection may be worked out.

Provide one or more water plugs, with several lengths of hose, at or near the shaft collar.

Provide one or more chemical fire extinguishers at or near the shaft collar, at every shaft station, and in dry timbered drifts distant from the shaft.

Provide a water plug with hose at every shaft station, and supply water either through a separate line from the surface or by tapping the water column. A shaft-sprinkling device may serve the same purpose.

Make the air line convertible into a water line.

Have a water barrel and buckets at stations even when there are hydrants and hose.

Provide dry extinguishers, such as sand, salt, or powdered limestone.

Provide at stations of working levels a box containing tools for carpenter and pipe work.

Arrange for the control of the ventilation through the use of doors.

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It is desirable to install reversible fans to insure a positive movement of air in fighting fires.

Provide air-tight fire doors for the isolation of parts of the mine.

Install fire doors in each level, if possible; also have fire doors at the top of the shaft, if the shaft house is combustible.

Have fire drills and a prearranged plan of action in case of fire.

Provide oxygen-breathing apparatus.

Provide fire signals.

Arrange to notify men and to get them to the surface promptly in case of a fire underground.

Do not throw water down a burning upcast shaft when there are men below and the ventilation is only natural; the current is liable to be reversed and the smoke and gases thus sent into the mine.

In providing a water supply for fighting fire it is far preferable to run a separate pipe line into the mine from the surface. Tapping the water column is less expensive, but this arrangement makes the supply dependent on the pumps. A barrel filled with water, with buckets nearby, is an efficient protective measure in dry stations. This should be used especially where there is no provision for water from the water column or a separate pipe line; even when such provision is made, the barrel is useful as an auxiliary in case something goes wrong. In cases of underground fires men have been known to pass by chemical extinguishers to look for water, probably because they did not understand the extinguishers.

Chemical extinguishers are excellent for quick work, but if they are installed it is important that sufficient men be instructed in their use. Also, the extinguishers should be kept properly charged. Plate I, *B*, shows the entrance to a powder magazine in a mine on the Gogebic range, with chemical fire-extinguishers near at hand and ready for instant use.

FIRE SIGNALS AND FIRE DRILLS.

Surface fire-alarm systems should include a system of signals to indicate fire at all shafts. In order that the engineer may be notified promptly of a fire, the signal code from underground should embrace a special alarm indicating that there is a fire and on what level of the mine. In this connection, the mine telephone is a useful device.

Usually it is the duty of the shift boss to notify miners in time of fire. Another method, in use at some mines, is to turn off the compressed air, this being a signal for all miners to report to the shaft. This signal could not be used, of course, on levels where the ground is broken by hand methods. Should the compressor break down and the fire signal be thus inadvertently given, miners would lose little

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time, for they would doubtless be sitting around waiting for the air to be supplied again.

In mines where the haulage roads are electrically lighted, a fire signal can be given by throwing the current off and on a certain number of times. However, this does not serve as a warning to men in the stopes and sublevels above the main haulage level.

Fire crews should be familiar with all fire-fighting equipment and should be drilled at stated intervals. There should be a prearranged plan of action to be followed in case of fire.

OXYGEN-BREATHING APPARATUS.

As part of the mine equipment for protection against fire underground, oxygen-breathing apparatus is invaluable. Such apparatus enables the wearer to perform hard labor in an atmosphere containing smoke, fumes, or poisonous gases. The apparatus should be kept in a place protected from hot air, steam, and dust; it should be kept clean and tested at frequent intervals to make sure that it is ready for instant use. Neglect of this precaution might result in the serious injury or death of the man wearing the apparatus; furthermore, it might result in fatal delay to men caught in a gas-filled mine. A sufficient supply of oxygen should be kept on hand at all times.

There should be at least two crews of five trained men—more would be better. No less than five men should be allowed in a party going underground during a mine fire. With any smaller number an accident to one of the party may prove fatal. The leader of the crew should be cool and deliberate and should take every precaution to protect the men under him. He should know the mine and understand the breathing apparatus thoroughly.

For a more detailed discussion of the use of breathing apparatus the reader is referred to Miners' Circular 4 of the Bureau of Mines.[a]

GASES ENCOUNTERED IN MINE FIRES.

In the Lake Superior iron mines, as in nearly all metal mines, the only gases that must be dealt with during a mine fire are carbon dioxide (CO_2) and carbon monoxide (CO). The exception to this statement in the Lake Superior region is from the burning of the combustible black slates of the Iron River-Crystal Falls district of the Menominee Range, in which sulphur dioxide (SO_2) is produced. Also, there have been reports from time to time of the presence of a small amount of an inflammable gas (not in explosive proportions) in the mine workings of this same district and in some of the mines near Iron Mountain, farther toward the south. At the Florence mine,

[a] Paul, J. W., The use and care of mine-rescue breathing apparatus, 1911, 24 pp., 5 figs.

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Florence, Wis., a short distance north of Iron Mountain, a drill hole sunk from the bottom of the mine is reported to have given off a hydrocarbon gas that when ignited burned with a blue flame. Such gas is of local occurrence, and reports of fires in the mines of the vicinity do not indicate that the gas has played any part in the loss of life or property.

Carbon dioxide (CO_2), or carbonic-acid gas is a product of complete combustion and must be dealt with in all mine fires. It is a colorless gas, without odor but with a slightly acid taste. Its specific gravity (air=1) is 1.529 at ordinary temperatures, but when highly heated it is expanded so that it may be lighter than cold air. It is produced by the burning of lamps, timber, or coal, by the breathing of men or animals, by the firing of explosives, and by the decay of timber or other vegetable matter.

The gas is seldom encountered in mine fires in sufficient quantity to cause poisoning, its effect being rather to replace the oxygen to such a degree that not enough oxygen is left to support life. Its first effect is to produce headache and dizziness and, in larger quantities, extreme panting. Air containing about 10 per cent of this gas will produce death in lengths of time depending upon the vitality of the subject. A candle will usually go out when the carbon-dioxide content of the surrounding air reaches about 3 per cent. The candle goes out not because of the presence of the carbon dioxide, but because of the lack of oxygen. Experiments have shown that a candle also goes out in air containing between 16 and 17 per cent oxygen.

Carbon monoxide (CO), even in very small quantities, is much more deadly than carbon dioxide. It is a product of the explosion of "powder" or of the incomplete combustion of wood or other combustible material. It is more likely to occur during a smoldering fire, such as might result in a damp or wet mine. Carbon monoxide is colorless and tasteless, and has a specific gravity of 0.969. It acts as a poison to the human system by combining with the haemoglobin of the blood and thus preventing that agent from absorbing the oxygen necessary to support life. One-tenth of 1 per cent of this gas, if breathed for a sufficient length of time, will render a human being unconscious and probably produce death. Larger proportions will produce death in relatively shorter periods of time. The gas can not be detected by the use of a candle, an important point, for many miners believe that wherever a candle will burn they can live. Its presence can be accurately determined only by a chemical analysis of the air. However, during mine fires, mice and birds, preferably canaries, may be used with advantage in determining the presence of

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carbon monoxide, as these animals succumb more quickly than a human being.[a]

A man usually has no warning of the effects of carbon monoxide; he suddenly becomes weak in the knees and falls unconscious.

The lower explosive limit (ignition by flame) of carbon monoxide and air requires 16.5 per cent of carbon monoxide, although inflammation may be had with as low as 12 per cent. In the absence of other explosive gases it would rarely be possible to get an explosive mixture of carbon monoxide from a mine fire, for the reason that in an open fire the oxygen in the atmosphere would be depleted below the combustion percentage long before the explosive percentage of carbon monoxide would be obtained. It is possible, however, that if a mass of timber were on fire and a current were passing through it a condition would be created like that in a coal or wood gas producer, as pointed out by Rice.[b] The carbon dioxide formed at the front edge fire might be broken up as it passed through the burning mass, with the resulting formation of carbon monoxide in large quantities. Fortunately this is a contingency that would rarely occur in a metal mine.

Hence it appears that in mine fires in the Lake Superior iron mines there need be little fear of encountering an explosive gas and that the use of safety lamps during mine fires is unnecessary. Nevertheless as a precaution it is desirable to have one or more safety lamps at hand for testing purposes.

THE USE OF ANIMALS IN MINE FIRES.

The presence of poisonous gases may be detected readily by the use of certain small animals. Even in cases where apparatus is available for the chemical determination of the constituents of the air, conditions might be such that it would be more desirable or even necessary to use an animal. As a result of many experiments, George A. Burrell, chemist of the Bureau of Mines, has prepared the following list showing the relative usefulness of small animals for such work: 1, canary; 2, mouse; 3, chicken; 4, small dog; 5, pigeon; 6, English sparrow; 7, guinea pig; 8, rabbit.

A canary will succumb to about one-tenth the proportion of poisonous gas required to overcome a man. Canaries and mice are most useful in exploration or rescue work during mine fires or after explosions.

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[a] See Burrell, G. A., The use of mice and birds for detecting carbon monoxide after mine fires and explosions: Technical Paper 11, Bureau of Mines, 1912, 15 pp.

[b] Rice, G. S., Mine fires, a preliminary study: Technical Paper 24, Bureau of Mines, 1912, p. 33.

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VENTILATION AS AFFECTING MINE FIRES.

Practically all Lake Superior iron mines depend on natural ventilation for supplying air underground. In many of them, however, especially those worked by the top slicing or sublevel slicing and caving system, it is necessary to augment the air supply in dead ends by opening the valves of the compressed-air pipes.

There are a few mines working with only one outlet, pending the completion of work looking toward a second outlet. In such cases air circulation is provided usually by a partition in the shaft, the compartment carrying the steam pipes being the upcast and the other compartment or compartments the downcast. A fire in such a shaft would impair the ventilation as soon as it destroyed the partition.

Most of the mines have two to four openings. As a rule the main workings are all well ventilated; it is usually under the timber mat and in dead ends that there is a lack of circulation. In many mines doors for the control of ventilation are to be found.

Control of air currents during a mine fire is of great importance. It is suggested that more attention should be paid to this subject, especially in dry, heavily timbered mines. The volume of air and the direction in which the air travels should be known. Doors should be provided at suitable points so that the circulation may be controlled. Fire doors should be so placed that it will be possible in time of fire to isolate any shaft from the near-by mine workings.

REVERSAL OF CURRENT.

Reversal of air current during a mine fire will cause the smoke and gases to seek escape through the opening that was previously the downcast. If men are escaping through such an opening, they may be overcome by the gases. If we assume that there is a fire in one of three shafts, all connected underground, the shaft in which the fire exists will upcast. Water played upon the fire, or into the shaft, will likely cause the current to reverse. Obviously, then, it is not safe to throw water on the fire until it is certain that all of the men are out of the mine. If, however, tight ventilation doors or fire doors are provided, they may be closed as the men leave the fire zone and the men will then be in no danger from smoke or gas. The doors will serve the further purpose of shutting off the supply of air from the fire and thus aid in extinguishing it.

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SEALING MINE FIRES.[a]

The sealing of shafts or mine workings is usually resorted to when there is no other convenient means of fighting a mine fire. In such cases much care should be observed to prevent the imprisonment of men within the sealed area.

In sealing the shaft collar the common method is to use planking well covered with manure or damp earth. If the fire has reached the surface, steel or iron rails may be thrown across the collar and steel plates pushed over the rails. When thus covered, loam, clay, or fine sand can be shoveled over the top and subsequently puddled.

For bulkheads underground, 2-inch by 12-inch planks covered with paper, the cracks being stopped with rags, have been used. In one case a double barrier of this kind, the barriers 3 feet apart and the intervening space filled with earth, was used. The safest device, and one that is always ready for use, is the iron door, which may be fitted into a masonry framework. There are several efficient designs of this type of bulkhead. The door proper may be made in two sections and kept standing in the drift, ready for use. Damp clay may be kept in a tub or barrel for stopping the cracks. Fire doors of this type are in use at the Newport mine, Ironwood, Mich. Where there is no haulage cable in the way the door may be hinged at the top and held ready to drop at instant notice.

The question of how soon seals or bulkheads may be removed with safety is often one of great importance. Rapidly rising water might make it necessary or desirable to reopen the sealed area at the earliest possible moment. The only sure method of determining when it is safe to remove the seal from an inclosed fire zone is by analysis of the confined air. Normal air contains, by volume, 20.7 per cent oxygen, the remaining 79.3 per cent consisting chiefly of nitrogen. When the percentage of oxygen is reduced to 16 or 16½ per cent a timber fire will begin to burn fitfully. It is safe to assume that in timber fires in metal mines there will be no flames when the content of oxygen within the sealed area reaches 14½ to 15 per cent. However, if there is a large mass of hot material, this will retain its heat for a long time, and meantime there will be slow oxidation without flame, so that the oxygen content, if the bulkheads are tight, will continue to drop until no oxygen remains.

FIRES IN THE COMBUSTIBLE BLACK SLATES OF THE MENOMINEE RANGE.

In many parts of the iron-bearing formation of the Menominee Range, but more especially in the vicinity of Iron River and Crystal

[a] See Rice, G. S., Mine fires, a preliminary study: Technical Paper 24, Bureau of Mines, 1912, 51 pp.; also Burrell, G. A., and Seibert, F. M., Gas analysis as an aid in fighting mine fires: Technical Paper 12, Bureau of Mines, 1912, 16 pp.

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Falls, Mich., and Florence, Wis., pyritiferous and carboniferous black slates are common, either as interbedded lenses or bands, or as the foot or the hanging wall of the ore body. The lenses or bands vary from a few inches up to many feet in thickness. These black slates, if they contain sufficient pyrite and carbonaceous matter, ignite spontaneously when exposed to the air under certain conditions. Several fires have occurred, and some are now burning in this rock, but in all cases investigated the fires were confined to the broken or crumbled rock. Although there are no records of lives having been lost in fires of this nature, much inconvenience and expense has been occasioned by them.

SOME RECENT FIRES.

FIRE AT THE BALTIC MINE.

At the Baltic mine, near Palatka, Mich., fires are burning at two points about 75 feet from the surface, where bands of black slate are exposed in a large open pit. The fires affect only a small area and have never caused any serious inconvenience.

FIRE AT THE DOBER MINE.

At the Dober mine, Stambaugh, Mich., black slate is encountered in large areas underground. For several years fires of supposed spontaneous origin have started in the rock pile on the surface where the slate has been dumped. This seems to be of such common occurrence that it is seldom a fire can not be found in some part of the black-slate dump.

FIRE AT THE FLORENCE MINE.

During the first week of October, 1905, some old timbers at the collar of No. 2 shaft, Florence mine, Florence, Wis., were burned. Sparks from this fire ignited the cribbing in No. 1 shaft, a short distance away. From the cribbing the fire communicated to the pyritic black slate in the hanging wall of the ore body. A great deal of inconvenience was experienced in fighting the fire, owing to the sulphurous fumes issuing from the opening, and it was not until some time during the week of October 16 that the shaft was finally filled with sand from a nearby pit. The mine records state that this fire started again in the spring of 1906, but no particulars are given. As work in the shaft was resumed in June of the same year it is presumed that the fire must have been out at that time.

FIRE AT THE YOUNGS MINE.

Early in 1911 fire started in the pyritic and carbonaceous black-slate footwall, just below the third level, of the Youngs mine, near

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Palatka, Mich. There had been a squeeze affecting a comparatively large area of the footwall, and a quantity of the rock had broken out and collected in a pile. The place was wet and some timber was mixed with the rock. At a time when no one was working in that part of the mine fumes were seen issuing from this pile of rock. The fire was supposedly of spontaneous origin. The sulphurous fumes soon filled the workings of the second and third levels, and it was decided to seal the fire by the use of bulkheads. After a great deal of difficulty this was accomplished on the second level. The men could work only a few minutes at a time, as they had no protection against the fumes except steam sprays. It was not until the footwall parts of the second, third, fourth, and fifth levels had been bulkheaded off that the fumes were prevented from filling the entire mine workings.

The bulkheads were removed early in January, 1913, and although the fumes hung in the workings for two or three months, constantly growing less noticeable, the fire had seemingly been extinguished.

FIRE IN BRISTOL OPEN PIT.

On February 20, 1913, fumes were seen issuing from a point about 100 feet below the surface in the north side of a large open pit at the Bristol mine, 1 mile west of Crystal Falls, Mich. The ore formation here contains several bands of combustible black slate. The footwall black slate is probably 300 feet in width. The fire, supposed to have been of spontaneous origin, started in a block of this rock about 50 feet thick that had sloughed off and settled some distance into the pit. The fire gradually gained headway until an area of approximately 100 square feet was affected. Early in May a trail was cut down the side of the pit to a point under the fire zone and a 2-inch water line was laid (Pl. II, *A*). The rock was excavated with pick and shovel and water was poured on the fire (Pl. II, *B*). In this way much headway was gained, but the work was abandoned on account of the possible danger of a slide of rock catching the fire fighters.

In July the fire was being held in check by the use of water. Although the rock was still very hot, the sulphurous fumes were barely noticeable.

DESCRIPTIONS AND ANALYSES OF BLACK-SLATE SAMPLES.

Following are descriptions and analyses of black-slate samples taken in the late winter and spring of 1913. The analyses were made by A. C. Fieldner, chemist, of the Bureau of Mines.

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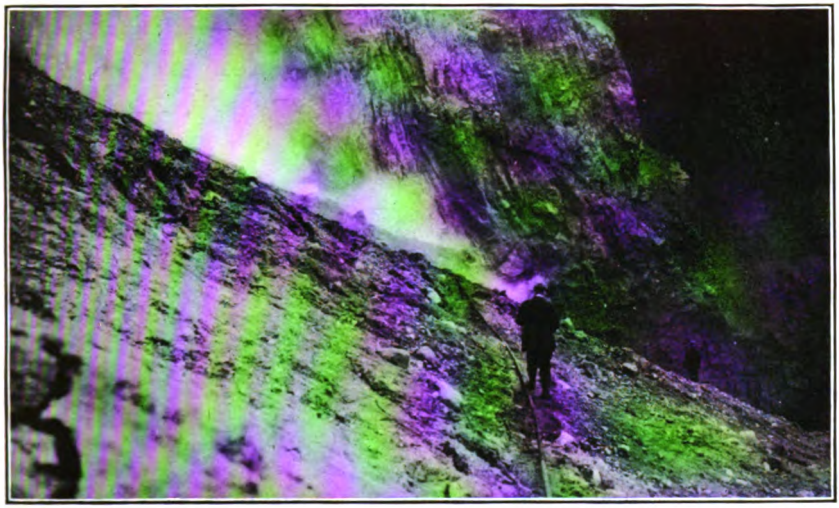

A. FIRE IN PYRITIFEROUS BLACK SLATE, IN SURFACE CAVE IN MINE NEAR CRYSTAL FALLS, MICH.

B. FIGHTING FIRE IN SURFACE CAVE IN MINE NEAR CRYSTAL FALLS, MICH.

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SAMPLE FROM THE DOBER MINE.

Designation and source of sample.—Laboratory No. 17026. Taken from a point 845 feet below the surface in the Dober mine, Stambaugh, Mich.

Character of sample.—Black slate of graphitic luster, with small particles of pyrite scattered throughout, especially on the surfaces of cleavage and bedding planes.

Analyses of black-slate samples from the Dober mine, Stambaugh, Mich.

PROXIMATE ANALYSIS.

Constituents.	Condition.			Referred to slate, moisture and ash free.
	Air dried.	As received.	Moisture free.	
Moisture	0.35	0.29	.....	.....
Volatile matter	10.75	10.76	10.79	50.09
Fixed carbon	10.72	10.72	10.75	49.91
Ash [a]	78.18	78.23	78.46	.....
	100.00	100.00	100.00	100.00

ULTIMATE ANALYSIS.

Hydrogen	0.30	0.29	0.26	1.21
Carbon	7.43	7.43	7.45	34.59
Nitrogen	.40	.40	.40	1.86
Oxygen	2.29	2.24	1.99	9.24
Sulphur	18.24	18.25	18.30	84.96
Ash	78.18	78.23	78.46	.....
	106.84	106.84	106.86	131.86
Soluble sulphur	0.16	0.16	0.16	0.74
Organic carbon	7.26	7.26	7.28	38.80
Organic hydrogen	.14	.14	.14	.65

[a] Ash includes oxygen absorbed by oxidation of FeS_2.

Calorific value calculated from ultimate analysis: 1,014 calories; 1,825 B. t. u.

Computed analysis of dry slate.

	Per cent.
Pyrite (FeS_2)	34.0
Sulphates of iron	.8
Other inorganic matter (slate, quartz, iron oxide, etc.)	55.9
Total inorganic matter	90.7
Organic carbon	7.3
Organic hydrogen	.1
Organic nitrogen	.4
Total organic combustible matter	7.8
Pyritic sulphur	18.14
Sulphate sulphur	.16
Total sulphur	18.30

SAMPLE FROM THE BALTIC MINE.

Designation and source of sample.—Laboratory No. 17027. Taken from a point 600 feet below the surface in the Baltic mine, Palatka, Mich.

Character of sample.—Same as that of Laboratory No. 17026.

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Analysis of black-slate sample from the Baltic mine, Palatka, Mich.

PROXIMATE ANALYSIS.

Constituents.	Condition.			Referred to slate, moisture and ash free.
	Air dried.	As received.	Moisture free.	
Moisture	0.73	0.73	.....	.....
Volatile matter	10.37	10.37	10.45	60.09
Fixed carbon	6.90	6.90	6.94	39.91
Ash	82.00	82.00	82.61	.....
	100.00	100.00	100.00	100.00

ULTIMATE ANALYSIS.

Hydrogen	0.61	0.61	0.53	3.05
Carbon	7.71	7.71	7.77	44.68
Nitrogen	.19	.19	.19	1.09
Oxygen	2.50	2.50	1.86	10.70
Sulphur	6.99	6.99	7.04	40.48
Ash[a]	82.00	82.00	82.61	.....
	100.00	100.00	100.00	100.00
Organic carbon	7.72	7.72	7.78	44.74
Organic hydrogen	.18	.18	.18	1.04
Soluble sulphur	.18	.18	.18	1.04

[a] Ash includes oxygen absorbed by oxidation of FeS_2.

Calorific value calculated from ultimate analysis: 884 calories; 1,591 B. t. u.

SAMPLE FROM THE YOUNGS MINE.

Designation and source of sample.—Laboratory No. 17058. Taken 250 feet below the surface at the Youngs mine, Palatka, Mich.

Character of sample.—Black slate containing bands of pyrite varying from thin veins of small particles to bands of solid pyrite one-eighth inch thick; fine pyrite was scattered throughout.

Analysis of black-slate sample from the Youngs mine, Palatka, Mich.

PROXIMATE ANALYSIS.

Constituents.	Condition.			Referred to slate, moisture and ash free.
	Air dried.	As received.	Moisture free.	
Moisture	1.08	1.11	.....	.....
Volatile matter	11.12	11.12	11.24	30.74
Fixed carbon	25.05	25.04	25.33	69.26
Ash[a]	62.75	62.73	63.43	.....
	100.00	100.00	100.00	100.00

ULTIMATE ANALYSIS.

Hydrogen	0.53	0.53	0.41	1.12
Carbon	20.85	20.84	21.07	57.62
Nitrogen	.47	.47	.48	1.31
Oxygen	3.14	3.17	2.20	6.02
Sulphur	19.62	19.61	19.83	54.23
Ash	62.75	62.73	63.43	.....
	107.36	107.35	107.42	120.30
Soluble sulphur	0.33	0.33	0.33	0.90
Organic hydrogen	.20	.20	.20	.55
Organic carbon	20.85	20.84	21.07	57.62

[a] Ash includes oxygen absorbed by oxidation of FeS_2.

Calorific value calculated from ultimate analysis: 2,170 calories; 3,906 B. t. u.

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Computed analysis of dry slate.

	Per cent.
Pyrite (FeS_2)	36.6
Sulphate of iron	.8
Other inorganic matter (slate, quartz, iron oxide, etc.)	40.7
Total inorganic matter	78.1
Organic carbon	21.1
Organic hydrogen	.2
Organic nitrogen	.5
Total organic combustible matter	21.8
Pyritic sulphur	19.50
Sulphate sulphur	.33
Total sulphur	19.83

SECOND SAMPLE FROM THE YOUNGS MINE.

Designation and source of sample.—Laboratory No. 16935. Taken 250 feet below the surface at the Youngs mine, Palatka, Mich.

Character of sample.—Same as that of Laboratory No. 17058.

Analysis of black-slate sample from the Youngs mine, Palatka, Mich.

PROXIMATE ANALYSIS.

Constituent.	Condition.			Referred to slate, moisture and ash free.
	Air dried.	As received.	Moisture free.	
Moisture	0.53	0.78	.....	.....
Volatile matter	9.77	9.75	9.83	45.55
Fixed carbon	11.70	11.66	11.75	54.45
Ash[a]	78.00	77.81	78.42	.....
	100.00	100.00	100.00	100.00

ULTIMATE ANALYSIS.

Hydrogen	0.50	0.53	0.44	2.04
Carbon	9.31	9.29	9.36	43.37
Nitrogen	.14	.14	.14	.65
Oxygen	2.44	2.65	1.98	9.18
Sulphur	15.38	15.34	15.46	71.64
Ash	78.00	77.81	78.42	.....
	105.77	105.76	105.80	126.88
Soluble sulphur	0.19	0.19	0.19	0.88
Organic hydrogen	.19	.19	.19	.88
Organic carbon	9.01	8.99	9.06	41.98

[a] Ash includes oxygen absorbed by oxidation of FeS_2.

Calorific value calculated from ultimate analysis: 1,165 calories; 2,097 B. t. u.

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SAMPLE FROM THE BRISTOL MINE.

Designation and source of sample.—Laboratory No. 17399. Taken 650 feet below the surface at the Bristol mine, Crystal Falls, Mich.

Character of sample.—Black slate with graphitic luster; pyrite fairly disseminated.

Analysis of dry slate from the Bristol mine, Crystal Falls, Mich.

	Per cent.
Pyrite (FeS_2)	16.84
Other inorganic matter (slate, quartz, etc.)	73.1
Total inorganic matter	89.9
Organic carbon	9.4
Organic hydrogen	.2
Organic nitrogen	.4
Total organic combustible matter	10.0
Total	99.9
Total sulphur [a]	8.98

SECOND SAMPLE FROM THE BRISTOL MINE.

Designation and source of sample.—Laboratory No. 17401. Taken 650 feet below the surface at the Bristol mine, Crystal Falls, Mich.

Character of sample.—Black slate with graphitic luster; contained some veins of quartz and numerous veins of small spherules of pyrite, scattered throughout.

Analysis of dry slate from the Bristol mine, Crystal Falls, Mich.

	Per cent.
Pyrite (FeS_2)	14.7
Other inorganic matter (slate, quartz, etc.)	78.6
Total inorganic matter	93.3
Organic carbon	6.5
Organic hydrogen	.1
Organic nitrogen	.3
Total organic combustible matter	6.9
Total	100.2
Total sulphur [a]	7.82

THIRD SAMPLE FROM THE BRISTOL MINE.

Designation and source of sample.—Laboratory No. 17398. Taken 650 feet below the surface at the Bristol mine, Crystal Falls, Mich.

Character of sample.—Very hard massive slate containing stringers of quartz and pyrite.

[a] All sulphur present as FeS_2.

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Analysis of dry slate from the Bristol mine, Crystal Falls, Mich.

	Per cent.
Pyrite (FeS_2)	16.9
Other inorganic matter (slate, quartz, etc.)	80.8
Total inorganic matter	97.7
Organic carbon	1.9
Organic hydrogen	.1
Organic nitrogen	.1
Total organic combustible matter	2.1
Total	99.8
Total sulphur [a]	8.99

FOURTH SAMPLE FROM THE BRISTOL MINE.

Designation and source of sample.—Laboratory No. 17397. Taken 650 feet below the surface at the Bristol mine, Crystal Falls, Mich.

Character of sample.—Hard massive slate; thin laminæ of pyrite between the layers.

Computed analysis of dry slate from the Bristol mine, Crystal Falls, Mich.

	Per cent.
Pyrite (FeS_2)	10.4
Other inorganic matter (slate, quartz, etc.)	87.5
Total inorganic matter	97.9
Organic carbon	1.4
Organic hydrogen	.1
Organic nitrogen	.2
Total organic combustible matter	1.7
Total	99.6
Pyritic sulphur	5.47
Sulphate sulphur	.08
Total sulphur	5.55

FIFTH SAMPLE FROM THE BRISTOL MINE.

Designation and source of sample.—Laboratory No. 17400. Taken 650 feet below the surface at the Bristol mine, Crystal Falls, Mich.

Character of sample.—Somewhat shaly slate with graphitic luster; contains veins of massive pyrite.

Analysis of dry slate from the Bristol mine, Crystal Falls, Mich.

	Per cent.
Pyrite (FeS_2)	20.1
Other inorganic matter (slate, quartz, etc.)	71.9
Total inorganic matter	92.0

[a] All sulphur present as FeS_2.

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	Per cent.
Organic carbon	7.0
Organic hydrogen	.3
Organic nitrogen	.3
Total organic combustible matter	7.6
Total	99.6
Total sulphur [a]	10.7

CHIEF ITEMS OF ANAYSES.

The accompanying condensed table of analyses allows a ready comparison of the results of analysis of the various samples. It will be noted that the last column shows the total combustible matter, organic carbon, hydrogen, and nitrogen being added to the pyritic sulphur.

Results of analyses of various black-slate samples.

Mine.	Laboratory No.	Pyrite (FeS_2).	Other inorganic matter.	Total inorganic matter.	Total organic combustible matter.[a]	Total sulphur.	Total combustible matter.[b]
Dober	17026	34.0	56.7	90.7	7.8	[c] 18.30	25.9
Baltic	17027						
Youngs	17058	36.6	41.5	78.1	21.8	[d] 19.83	41.3
Do	17399	16.8	73.1	89.9	10.0	[e] 8.98	19.0
Bristol	17401	14.7	78.6	93.3	6.9	[e] 7.82	14.7
Do	17398	16.9	80.8	97.7	2.1	[e] 8.99	11.1
Do	17397	10.4	87.5	97.9	1.7	[f] 5.55	7.2
Do	17400	20.1	71.9	92.0	7.6	[e] 10.70	18.3

[a] Includes carbon, hydrogen, and nitrogen.
[b] Includes organic matter and pyritic sulphur.
[c] Includes 0.16 per cent sulphur combined as iron sulphate.
[d] Includes 0.33 per cent sulphur combined as iron sulphate.
[e] Includes 0.08 per cent sulphur combined as iron sulphate.
[f] All sulphur as FeS_2.

CAUSES OF SPONTANEOUS IGNITION.

Chemical and other investigations of the combustible black slates, as far as carried on by the Bureau of Mines, have been of a preliminary nature only. The spontaneous combustion of the slates and the resulting danger to the miners suggest the need of studying all the factors involved, namely, the percentage of pyrite, under various physical conditions, that may be necessary to cause ignition of the rock; the relation of the carbonaceous matter to the heat-producing reactions; and the possibility of the presence of some other mineral or minerals that might be related in some way to the spontaneous ignition of the rock.

It may be assumed broadly, however, that the heat necessary for combustion is probably generated by the oxidation of the pyrite and by the crushing and crumbling of the rock. A most important factor seems to be the presence of finely divided masses or crystals of pyrite intimately mixed with carbonaceous matter and disseminated through-

[a] All sulphur present as FeS_2.

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out the rock. It is probable that the heat developed by crushing is not always of importance, for there are several instances of spontaneous ignition of the rock within 2 or 3 feet of the surface of dumps. Obviously, for the rapid oxidation of the pyrite fine division and free access of air are necessary, and these conditions are fulfilled in piles of broken or crushed rock.

METHODS OF PREVENTING AND FIGHTING SPONTANEOUS FIRES.

Theoretically, there is no danger of the spontaneous ignition of the rock in place, for oxidation of the pyrite can not proceed without the presence of air. In all the fires of this nature that were investigated by the writer combustion was confined to broken, crushed, or crumbled rock. It seems, then, that operators of mines in those districts of the Menominee range where combustible black slates occur should observe the following precautions:

(1) Combustible black slate should not be dumped in abandoned places underground.

(2) Broken rock should not be allowed to accumulate underground; it should be hoisted to the surface promptly.

(3) In choosing a method of mining due consideration should be given to the presence of combustible rock, and a system should be selected that will prevent, as far as possible, the exposure, crushing, or squeezing of the rock underground.

It should be remembered that as mining increases in depth the squeezing and crushing of the rock will be greatly increased.

Fires in pyritic rocks are difficult to control. An open-pit fire may not be dangerous, unless it be close to a downcast connecting with the underground workings of the mine. No satisfactory rules can be promulgated for fighting such fires. The first problem is usually that of a safe approach to the affected area. If it is accessible the rock may be excavated and water introduced. It may be possible to do this by using a large stream of water under high pressure. Inert gases, such as carbon dioxide, may be introduced through pipes or by pressure from underground. With this method, however, it is necessary to seal the surface with some plastic material.

In underground fires, as well as those exposed at surface, any method of fighting that cuts off the supply of air will be effective. Probably the best means of cutting off the air supply is through the use of bulkheads, preferably of masonry. Combustion within the isolated section may be further retarded by the introduction of some inert gas. Care should be observed not to remove the seals until it has been determined, through careful analysis of the inclosed atmosphere, that combustion can not exist.

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Flooding the workings with water is effective. However, pyritic fires extinguished by water or by sealing may start again, even after the lapse of several months. In the case of the Florence mine fire, mentioned on another page, air was cut off from the burning rock by filling the shaft with sand. The fire was supposedly extinguished, but after a few months it began burning afresh.

ACKNOWLEDGMENTS.

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PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larson, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 53. Mining and treatment of feldspar and kaolin in the southern Appalachian region, by A. S. Watts. 1913. 171 pp., 16 pls., 12 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 60. Hydraulic mine filling; its use in the Pennsylvania anthracite region; a preliminary report, by Charles Enzian. 1913. 77 pp., 3 pls., 12 figs.

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BULLETIN 65. Oil and gas wells through workable coal beds; paper and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

BULLETIN 70. A preliminary report on uranium, radium, and vanadium, by R. B. Moore and K. L. Kithil. 1913. 100 pp., 4 pls., 2 figs.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 29. Training with mine-rescue breathing apparatus, by J. W. Paul. 1912. 16 pp.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 8 figs.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 41. Mining and treatment of lead and zinc ores in the Joplin district, Missouri, a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.

TECHNICAL PAPER 53. Proposed regulations for oil and gas wells, with comment thereon, by O. P. Hood and A. G. Heggem. 1913.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

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MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 7. The use and misuse of explosives in coal mining, by J. J. Rutledge. 1913. 53 pp., 4 figs.

MINERS' CIRCULAR 8. First-aid instructions for miners. M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 65 pp., 46 figs.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

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